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# Application and Progress of Insulin Delivery Devices in Diabetes Management

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**Abstract:** With continuous advancements in diabetes management technology, insulin delivery devices are playing an increasingly important role in diabetes treatment. The application of various technologies, such as insulin pens and insulin pumps, plays an essential role in the management of type 1 diabetes (T1DM) and type 2 diabetes (T2DM). Insulin pens, known for their convenience and dosing accuracy, have been widely used among T2DM patients, and recent developments in smart insulin pens have further improved patient adherence and glycemic control. Insulin pumps, particularly patch pumps, provide more precise blood glucose management for T1DM and some T2DM patients, significantly reducing glycemic variability and the risk of hypoglycemia. As an innovative insulin delivery device, patch pumps are characterized by their compact, lightweight, and tubeless design, making them particularly suitable for patients seeking a discreet and convenient user experience. Nevertheless, further optimization is needed in the display of dosage and key parameters to ensure real-time and clear monitoring of insulin delivery, thereby assisting patients and clinicians in making timely adjustments to treatment plans. This review summarizes the advantages and disadvantages of different types of insulin delivery systems and discusses their future directions in clinical applications. The further advancement of these systems holds promise for providing safer, more convenient, and precise treatment experiences for diabetes management.

**Keywords:** Diabetes; Insulin delivery system; Insulin pen; Electronic pump; Mechanical patch pump

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## 1. Introduction

Diabetes is a metabolic disorder characterized by chronic hyperglycemia. According to clinical manifestations and etiologies, diabetes is generally classified into type 1 diabetes mellitus (T1DM), type 2 diabetes mellitus (T2DM), gestational diabetes, and other special types. China has a huge number of diabetic patients, and diabetes and its complications have become a major public health burden [1]. Therefore, further exploration of effective treatment methods is of great significance for blood glucose control in patients.

Patients with T1DM and advanced T2DM usually suffer from pancreatic β-cell failure, and insulin therapy serves as a vital treatment modality [2]. Remarkable progress has been made in insulin therapy in recent years, including advances in long-acting basal insulin, rapid-acting prandial insulin, as well as injection and infusion devices. These innovations have improved blood glucose control in diabetic patients and reduced the risk of hypoglycemia [3]. Insulin therapy technology has evolved significantly from traditional vials and syringes to modern insulin pens and insulin pumps. These technological innovations have not only improved the accuracy and convenience of insulin infusion, but also greatly elevated patients' quality of life. The emergence of insulin infusion devices has provided a more advanced and personalized management tool for diabetic patients, especially those requiring precise blood glucose control. Starting from the principles and evolution of insulin infusion devices, this paper further explores their applications in diabetes management, so as to conduct a comprehensive review of the current application status of such devices.

## 2. Principles and progress of insulin infusion devices

Insulin infusion devices are equipment for diabetes management designed to simulate natural pancreatic insulin secretion by delivering insulin continuously or intermittently into patients' bodies to maintain stable blood glucose [4]. Current research and development of insulin infusion devices are gradually focusing on achieving stricter blood glucose control while reducing the incidence of hypoglycemia. With continuous technological advances, insulin infusion devices have been progressively upgraded, achieving notable progress in improving infusion precision, minimizing therapeutic invasiveness, and lowering patients' treatment burden. Insulin infusion devices mainly include insulin pens and insulin pumps. Continuous subcutaneous insulin infusion (CSII) via insulin pumps can better mimic physiological insulin secretion, and insulin pumps fall into three main categories: traditional pumps connected to subcutaneous infusion sets through catheters; patch pumps that attach directly to the skin without tubing (including mechanical types such as CeQur and V-Go, software-driven types such as Omnipod and MicroTech, as well as patch-type products covered by Chinese patents CN202411057395.9 and CN202411282861.3 from Sinotech & wellcare; see **Figure 1**); and implantable pumps that deliver insulin into the peritoneal cavity via surgical implantation. Each type of pump has unique strengths and weaknesses, offering diversified options for diabetic patients with different needs. **Table 1** summarizes the types, working mechanisms, advantages, disadvantages, and applicable populations of insulin infusion devices, while **Table 2** further distinguishes the characteristics of various patch pumps.

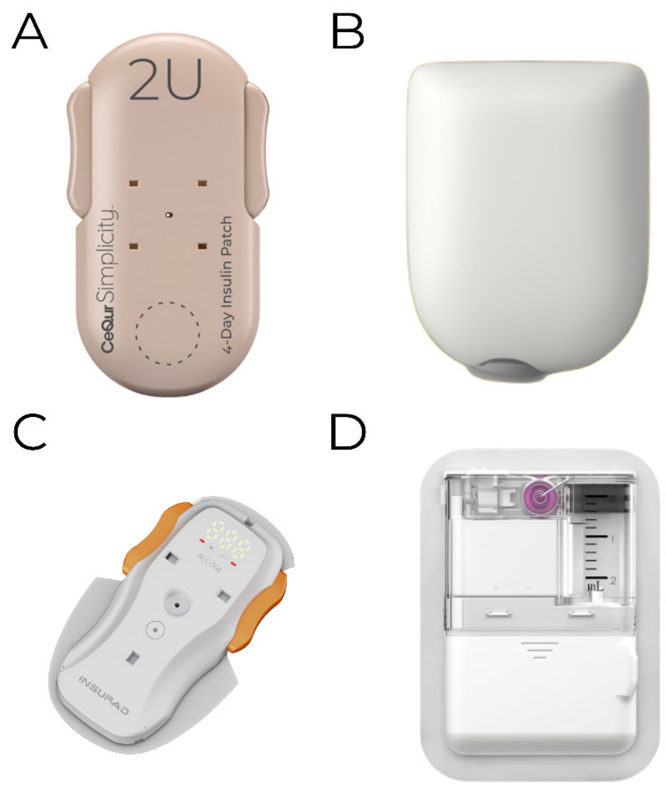


**Figure 1.** Schematic diagram of different types of insulin patch pumps.

A: CeQur; B: Omnipod; C: Products under Chinese Patents CN202411057395.9 and CN202411282861.3; D: MicroTech.

**Table 1.** Types, working mechanisms, advantages, disadvantages, and applicable populations of insulin infusion devices

| Device type | Working mechanism | Advantages | Disadvantages | Applicable populations |
|---|---|---|---|---|
| Insulin pen | Manual insulin injection | 1. Convenient and easy to operate<br>2. Accurate dosing<br>3. Smart insulin pens can connect with mobile applications to boost treatment adherence | 1. Lack of automatic functions<br>2. Require self-management by patients<br>3. Unsuitable for patients requiring frequent injections | 1. T2DM patients in need of simple dosage management tools<br>2. Elderly patients and those with visual or dexterity impairments |
| Conventional insulin pump | A small infusion cannula inserted under the skin is connected to the pump via plastic tubing for insulin delivery | 1. Users can set customized continuous basal insulin infusion rates according to individual conditions<br>2. Better simulation of physiological insulin secretion | 1. Bulky size may restrict movement<br>2. Tubing may kink or detach<br>3. Regular catheter replacement is required | T1DM patients requiring intensive insulin management and frequent dosage adjustments |

| | | | | |
|---|---|---|---|---|
| Patch insulin pump | Insulin is delivered directly through skin-attached devices without external tubing | 1. Tubeless, lightweight and low-profile design<br>2. Greater freedom of movement<br>3. More cost-effective and easier to operate compared with traditional pumps | 1. Frequent device replacement required<br>2. Risk of catheter blockage<br>3. Limited basal rate adjustment capacity compared with traditional pumps | 1. T2DM patients prioritizing convenience and mobility<br>2. Young patients preferring modern solutions<br>3. Patients with relatively stable insulin demand |
| Implantable insulin pump | Surgically implanted device delivers insulin continuously into the peritoneal cavity via internal catheters | 1. Stable long-term insulin infusion<br>2. Intraperitoneal injection improves insulin absorption efficiency<br>3. Less patient intervention required compared with external pumps | 1. High procurement cost<br>2. Surgical implantation is mandatory<br>3. Risk of postoperative complications<br>4. Requires regular medical follow-ups | 1. Patients facing prominent difficulties in daily insulin management<br>2. Patients requiring stable and predictable insulin delivery |

**Table 2.** Characteristics of different types of patch insulin pumps

| Device type | Working mechanism | Advantages | Disadvantages | Applicable populations |
|---|---|---|---|---|
| Mechanically driven (CeQur, V-Go) | Mechanical structures such as springs and pistons realize quantitative insulin delivery without electronic components or batteries | 1. Simple structure and easy operation<br>2. No power supply needed, lowering risks of electronic failures<br>3. Compact and discreet for skin attachment | 1. Relatively single functions, lacking intelligent management modules<br>2. Real-time adjustment of infusion rates is unavailable | 1. T2DM patients requiring basal and prandial insulin delivery<br>2. Patients hoping to simplify insulin management and reduce daily injection frequency |
| Software-driven (Omnipod, MicroTech) | Built-in electronic control systems regulate insulin delivery via software algorithms and can link with continuous glucose monitoring (CGM) to realize automated insulin infusion | 1. Support personalized and precise insulin management<br>2. Can connect with CGM to form closed-loop systems for automatic infusion adjustment<br>3. Abundant data for physicians and patients to monitor and adjust treatment regimens | 1. Require regular charging or battery replacement<br>2. Complex systems demand longer learning and adaptation periods | 1. Patients requiring precise blood glucose control<br>2. Patients hoping to minimize manual operations and improve quality of life |
| Patch-type (Sinotech & wellcare patents CN202411057395.9, CN202411282861.3) | Mechanical or electronic insulin control with patch design, highlighting tubeless convenience and wearing comfort | 1. No external tubing to reduce restraint and improve wearing comfort<br>2. Simple to learn and operate<br>3. Firm adhesion suitable for various daily activities | 1. Limited insulin storage volume, requiring frequent replacement<br>2. May lack advanced functions such as CGM linkage | 1. Patients requiring precise blood glucose control<br>2. Patients pursuing a more comfortable and convenient insulin delivery experience |

## 3. Application of insulin infusion devices in diabetes management

### 3.1. Application in type 1 diabetes mellitus

Type 1 diabetes accounts for 5–10% of global diabetic cases with an increasing incidence in recent years, and no radical cure is available; patients require lifelong long-term management. Insulin pens are widely adopted for multiple daily injections (MDI) and have undergone continuous iterative upgrades. Nevertheless, sufficient research evidence is still lacking to confirm the definite clinical advantages of smart insulin pens over conventional ones.

The application of insulin pump therapy in T1DM management has grown over the past two decades, with utilization rates reaching 40–60% among patients in some Western countries. Domestic and international guidelines, as well as large registry studies, have demonstrated that insulin pumps can improve blood glucose control via programmable basal rates, prandial boluses, and temporary basal rates. When combined with continuous glucose monitoring (CGM) and automated insulin delivery (AID) algorithms, closed or semi-closed therapeutic systems can be constructed [5]. Compared with MDI in adult T1DM patients, insulin pumps generally induce a mild reduction in HbA1c, with clinically meaningful improvements more likely to occur in patients with poor baseline glycemic control. The overall risk of severe hypoglycemia is equivalent or slightly lower, and quality of life is generally improved. In children and adolescents with T1DM, insulin pumps feature flexible and adjustable infusion volumes, yet randomized controlled trials show weaker benefits than in adults, manifested as a slight decline in HbA1c with no significant differences in the incidence of severe hypoglycemia or diabetic ketoacidosis, while quality of life and treatment satisfaction are comparable or higher [6]. Domestic Chinese research data also support the clinical value of CSII in pediatric T1DM. A retrospective CGM study enrolling 362 Chinese T1DM patients found that the CSII group achieved lower HbA1c and fasting blood glucose levels, higher time in range (TIR), and lower time above range (TAR) compared with the MDI group, while no significant difference was observed in hypoglycemia risk [7]. Overall, CSII better simulates physiological insulin secretion patterns and delivers certain clinical benefits in blood glucose control, safety, and cost-effectiveness.

### 3.2. Application in type 2 diabetes mellitus

Insulin pens are currently the most widely used insulin delivery modality for T2DM patients. Over the past decade, remarkable progress has been achieved in insulin pen design. Memory-enabled insulin pens can store and display historical injection time and dosage data, which are particularly valuable for patients with cognitive impairment or complex dosage regimens that hinder active disease management. More importantly, smart insulin pens integrate such functions with CGM data and upload information to online platforms, enabling medical professionals to review and adjust treatment plans [8] remotely. Studies have indicated that patients with poor insulin dosage adherence tend to have suboptimal blood glucose control. Therefore, smart pens may serve as an effective tool for early identification of patients in need of educational and behavioral interventions. However, no studies have specifically investigated the impacts of smart pen usage on blood glucose control, quality of life, or cost-effectiveness in T2DM populations.

#### 3.2.1. Application of conventional insulin pumps in T2DM

The number of T2DM patients using insulin pumps has risen in recent years, as the benefits of CSII widely validated in T1DM populations may also apply to T2DM patients [9]. Multiple studies have evaluated the effects of CSII in T2DM subjects, yet discrepancies exist in trial design, methodology, pump selection, and participant demographics. In the OpT2mise trial, researchers implemented a two-month standardized titration preparation period including basal and prandial insulin adjustment to optimize dosages, then randomly assigned patients with persistently suboptimal glycemic control to the CSII group or MDI group. The CSII group received basal insulin infusion accounting for 50% of total daily insulin dosage. At the 6-month follow-up, the HbA1c reduction in the CSII group was approximately 1.1%, versus 0.4% in the MDI group ($p < 0.001$). Twelve-month follow-up data showed sustained therapeutic effects for patients initially treated with CSII, and similar improvements were observed for participants switching from MDI to CSII after six months [10]. Other trials also adopted pre-CSII preparation periods with varying durations. A Chinese multicenter study demonstrated that the 1-year remission rates among 382 newly diagnosed T2DM patients were 51.1% for the CSII group, 44.9% for the MDI group, and 26.7% for the oral hypoglycemic agent group. Another domestic inpatient T2DM study found that sensor-augmented pumps (SAP) shortened time to glycemic targets compared with MDI ($3.7 \pm 1.1$ days vs. $6.3 \pm 3.1$ days, $p < 0.001$), with more patients achieving target glucose levels within 3 days (21 cases vs. 6 cases) [11]. Based on most existing clinical research, head-to-head clinical data and long-term outcome comparisons remain insufficient for different insulin pump types across various T2DM subgroups.

### 3.2.2. Application of mechanical patch pumps in T2DM

Compared with conventional insulin pumps, mechanical patch pumps feature a compact size, lightweight design, tubeless structure, and soft subcutaneous cannulas, making them more suitable for daily insulin management of some T2DM patients. Most existing electronic insulin pumps are developed for T1DM treatment, equipped with refined carbohydrate calculation, multiple basal rate settings, and semi-automatic or automatic infusion functions. However, such complex features may be unnecessary for most T2DM patients and increase operational complexity and educational costs [12]. Difficult pump operation, high equipment expenses, and demanding training are major barriers limiting the popularization of CSII in T2DM. Sufficient understanding of pump functions and continuous intensive training are critical for the safe use of software-driven smart pumps; inadequate training may lead to misoperation and elevated risks of severe hypoglycemia or diabetic ketoacidosis [13]. In contrast, mechanical patch pumps offer simplified functions, convenient operation, and favorable cost-effectiveness, which may facilitate long-term utilization and grassroots promotion among T2DM patients.

Mechanical patch pumps designed for T2DM patients have been launched in Europe and the United States. Mader et al. evaluated the safety and efficacy of the CeQur PAQ mechanical patch pump, and the results showed that patients' HbA1c decreased from 8.6% to 7.1% ($p < 0.0001$), total daily insulin dosage increased by 12.1 U ($p = 0.0058$), and the frequency of prandial insulin administration rose significantly ($p = 0.0081$). Hermanns et al. further found that PAQ alleviated insulin use barriers among patients previously receiving MDI therapy, especially injection phobia and pessimistic expectations for treatment outcomes. By shortening administration time and minimizing interference with daily activities, it improved insulin treatment adherence. Other research indicated that 77.8% of patients preferred mechanical patch pumps over insulin pens for prandial insulin delivery, 88.6% reported fewer portable diabetes supplies to carry, and 84.4% gained greater freedom in disease management.

V-Go represents another category of mechanical patch pumps. A retrospective study by Sutton et al. showed that adult diabetic patients using V-Go for 14 months achieved a 1.67% reduction in HbA1c. Patients previously on MDI reduced total daily insulin dosage by 17 U ($p < 0.0001$), with monthly pharmacy costs cut by approximately 25 USD per patient. Cost analysis revealed that the incremental increase in diabetes medication expenses was lower for the V-Go group relative to MDI; for every 1% reduction in HbA1c, the incremental cost was 695.61 USD less than that of conventional insulin pumps [14]. Domestic research also suggested that patch pumps may outperform traditional pumps and multiple subcutaneous injections for T2DM patients. Studies demonstrated that after two weeks of treatment, the patch pump group recorded lower fasting blood glucose, 2-hour postprandial blood glucose, bedtime blood glucose, and HbA1c levels, shortened time to glycemic targets, and reduced insulin dosage, accompanied by improved adherence and satisfaction as well as lower hypoglycemia incidence (all $p < 0.05$). Among newly diagnosed T2DM patients receiving 12-week intensive patch pump therapy, HbA1c, 2-hour postprandial, and fasting blood glucose levels were lower than those in the MDI group. Three-month follow-up showed a lower hypoglycemia rate, reduced insulin consumption, and shorter time to reach glycemic targets (all $p < 0.05$). Short-term intensive insulin pump therapy also delivered higher response rates (97.2% vs. 91.2%) and lower hypoglycemia rates (4.4% vs. 10.8%). Despite higher upfront costs, the overall economic burden was comparable to conventional therapies when achieving equivalent glycemic control effects. In general, mechanical patch pumps hold potential to simplify operations, improve adherence, and optimize blood glucose control, yet more long-term, head-to-head, and cost-effectiveness studies are required to verify their applicable populations and real-world clinical value.

### 3.3. Application of insulin infusion devices in pregnant patients

In early pregnancy, insulin sensitivity increases in women with diabetes, so blood glucose levels need to be closely monitored to reduce the risk of hypoglycemia. However, after the 16th week of gestation, insulin resistance gradually rises in patients with pre-existing diabetes, and insulin doses usually require weekly adjustment. Insulin requirements may increase across different stages of pregnancy. A study by Skajaa et al. demonstrated that insulin requirements in mothers with T1DM grow progressively with increasing parity. For women with T2DM managed through diet, oral medications, or basal insulin, education on intensive insulin management before or during pregnancy is critical to achieving optimal glycemic control. Insulin remains the cornerstone of diabetes management during pregnancy, as it effectively lowers blood glucose without crossing the placenta and thus has favorable safety.

Available studies indicate that gestational diabetes mellitus (GDM) mothers receiving insulin pump therapy may achieve better glycemic control and fewer adverse neonatal complications compared with those treated with basal-bolus insulin therapy. For mothers with pregestational diabetes, both multiple daily injections (MDI) and continuous subcutaneous insulin infusion (CSII) are considered viable treatment strategies, yet current evidence is insufficient to recommend one approach over the other conclusively. If CSII is planned for use, initiation prior to pregnancy is advised to allow patients adequate time for adaptation and attainment of optimal glycemic control. Additionally, women using CSII should formulate an emergency plan for subcutaneous insulin administration to address potential pump malfunction. A pre-specified analysis conducted within the CONCEPTT trial compared glycemic control and pregnancy outcomes between women with T1DM treated with MDI and those treated with CSII. The results showed superior glycemic control and lower rates of gestational hypertension, neonatal hypoglycemia, and neonatal intensive care unit admission in the MDI group, even though insulin delivery methods were not randomly assigned [15]. Further research is warranted to identify more effective therapeutic regimens.

## 4. Conclusion

This article reviews the application progress and clinical value of insulin infusion devices in diabetes management. Insulin pens have become a commonly used insulin administration method for patients with T2DM owing to their convenient operation and relatively accurate dosage delivery. With the development of smart insulin pens, functions such as injection time recording, dosage logging, and data uploading help improve medication traceability and may optimize the quality of management for patients on complex treatment regimens or those with cognitive impairment. Nevertheless, their long-term impacts on glycemic control, quality of life, and cost-effectiveness, as well as their advantages over novel insulin pumps, remain to be verified in further clinical studies.

Insulin pumps deliver more refined insulin infusion for patients with T1DM and some patients with T2DM, and are particularly suitable for populations with poor glycemic control, significant blood glucose fluctuations, or high hypoglycemia risks. Mechanical patch insulin pumps require no external tubing and can be attached directly to the skin, lowering the risk of infusion interruption caused by catheter dislodgement or blockage, and presenting potential strengths in enhancing mobility convenience, reducing treatment burdens, and improving patient experience. However, such devices still require optimization in aspects including real-time infusion monitoring, dosage visualization, display of key parameters, wearing duration, and wear stability. Future integration with automated insulin delivery (AID) algorithms, continuous glucose monitoring, and more sophisticated display systems will help boost patient confidence and facilitate clinical decision-making.

Overall, the iteration of insulin infusion devices has driven the transformation of diabetes treatment from empirical drug administration to individualized and precision management. With simplified operation, favorable portability, and potential cost advantages, mechanical patch pumps may serve as an important complement to insulin therapy for diabetes. Future studies should establish a systematic evaluation framework covering safety, effectiveness, cost-effectiveness, patient education burden, and low-cost accessibility based on real-world usage scenarios, so as to clarify their applicable populations and long-term clinical value.

## Disclosure statement

The authors declare no conflict of interest.

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